CIVIL AERONAUTICS BOARD

ACCIDENT INVESTIGATION REPORT

Adopted June 29, 1949 Released: June 30, 1949

NORTHWEST AIRLINES, INC.—WINONA, MINNESOTA—AUGUST 29, 1948

The Accident

Northwest Airlines' Flight 421, aircraft NC-93044, a Martin 202, en route from Chicago, Illinois, to Minneapolis, Minnesota, crashed near Winona, Minnesota, at approximately 1705,* August 29, 1948. All of the 37 occupants were killed, and the aircraft was destroyed.

History of the Flight

Northwest Airlines' Flight 421 departed from Chicago for Minneapolis at 1550, August 29, 1948. On board were 33 passengers, four crew members, 800 gallons of fuel, and 1,038 pounds of baggage. Total aircraft weight was 38,015 pounds which was within the certificated limit and it was properly loaded in reference to the center of gravity. Weather information available to the flight prior to departure indicated that relatively good flying conditions existed en route with the exception of scattered rain showers and thunderstorms which were in the vicinity of La Crosse, Wisconsin, and Rochester, Minnesota.

Routine position reports were received from the flight as it progressed on course at its flight plan altitude of 8,000 feet. At 1655, one hour and five minutes after takeoff from Chicago, the flight reported over La Crosse, 125 miles southeast of Minneapolis, and was at that time cleared to start an en route descent. Four minutes later, at 1659, the flight reported passing through the 7,000-foot altitude level. No indication of any trouble was contained in this transmission. This was the last word heard from the flight.

Between 1645 and 1700 several persons in the vicinity of Winona, Minnesota, approximately 95 miles southeast of Minneapolis, were watching a thunderstorm which was approaching from the northwest. As the storm moved over Winona, the wind increased in intensity and considerable lightning and thunder were observed At this time, about 1705, Flight 421 was seen flying below the overcast As it passed over Winona, the aircraft appeared to enter the roll cloud or the leading edge of the thunderstorm at which time it was lost from view. Seconds later parts of the airplane were observed falling It was later found that the flight had crashed approximately 4 miles northwest of Winona on a bluff on the east side of the Mississippi River

Investigation

The wreckage consisted of four large airplane sections and a large number of small pieces. The large sections fell in a straight line on a bearing 335 degrees, which approximated the intended course of the flight. Two miles to the north of Winona the outer portion of the left outer wing was found. This part consisted of the wing structure ahead of the left aileron It had sustained little damage. A blue painted piece of fuselage structure was found imbedded in the leading edge.

Progressing in the direction of the aircraft's flight, 0.7 of a mile from the left outer wing section, the tail assembly and the part of the fuselage to which the tail surfaces attach were found in the upright position. The left side of this fuselage section was torn diagonally aft from top to bottom through the left rear escape hatch. This tear was made in a downward and forward direction. The right side of this fuselage section was torn irregularly and also in a downward and forward direction similar to that of the left side. The vertical fin and rudder were in good condition, only a few wrinkles appearing in the skin of the fin. No damage resulted to the rudder which was capable

*All times referred to herein are Central Standard and based on the 24-hour clock

of rotating freely, and the control cables remained attached to the rudder quadrant. The horizontal stabilizer and elevators were bent, scratched and broken from impact forces when the assembly struck the ground. A piece of skin from the trailing edge of the left wing flap was found imbedded in the leading edge of the right horizontal stabilizer.

The third section of the aircraft, the inner-portion of the left outer wing, was located 35 of a mile northwest of the tail section, parts of the flap and the flap vane were still attached. It was a piece of the trailing edge of this wing flap that was found imbedded in the right horizontal stabilizer This section of the wing had parted from the center section of the wing at station 187, the location of the wing root fitting.

The last and major portion of the aircraft wreckage was found 0.75 of a mile from the inner portion of the left outer wing. It covered an area of approximately 300 feet in diameter. Here were located the engines and propellers, most of the fuselage, the entire right wing, and the center section of the left wing. From an examination of this wreckage it was determined that the landing gear had been in the up position, and that the flaps had been retracted at the time of the accident. All safety belts were broken, and no seats were found attached to the floor mountings.

Engines and propellers were examined at the scene of the accident. No evidence was found that there had been any mechanical failures in either the engines or the propellers prior to the time that they struck the ground. Propeller blade markings, and breaks indicated that only small rotational forces were present at the time of impact.

An examination of radio and electrical equipment revealed no indication of any malfunctioning prior to the time of the accident, nor was there evidence that any of this equipment had been damaged by lightning or static discharges. The master switch for the airplane was found in the off position.

Portions of the wreckage were removed from the scene of the accident for tests and detailed examination. These included the left wing outer panel in two parts, the attachment end of the left wing front spar lower flange, the attachment end of the left wing rear spar lower flange and dihedral wedge, the left wing structure including the landing gear well, the right wing structure including the dihedral wedges of the front and rear spars, the right stabilizer and elevator, and the flaps and ailerons. Most significant of these parts were the attachment ends of the front spar lower flanges, and the dihedral wedges. These parts constituted the wing root fittings in which, as will be later explained, fatigue failure was found.

The outer wing front and rear lower spar flanges attach to the center wing front and rear lower spar flanges by means of a dihedral wedge as illustrated in the attached drawing. Originally, the spar flanges were bolted directly together, but tests of the prototype airplane demonstrated a need for a greater lateral stability. Therefore, the outer wing was rotated seven degrees upward by means of incorporating the dihedral wedge in the attachment of the outer wing to the center section. It will be noted in the drawing of this part that the attachment ends of the lower spar flanges and dihedral wedge have four steps or vertical increases in thickness. In each step the vertical increase in thickness is approximately 13/64 of an inch, except for the fourth step inboard on the center section spar flange where the vertical increase in the thickness is approximately 3/4 of an inch. The radius in the fillet of these steps is approximately 1/8 of an inch.

Evidence indicated that the outer wing had first separated from the center section in the fillet of the fourth step of the lower front center section spar flange. Examination of this fracture revealed that the separation had started from a fatigue crack approximately 7/8 of an inch long, and 3/32 of an inch deep, the remaining cross section of the material at this point failing from tension.

In conjunction with the study of the structural parts of NC-93044, parts of another Martin 202, NC-93042 were examined. This second airplane had completed a flight from Chicago to Minneapolis shortly after the scheduled flight of NC-93044 during which the pilot experienced average turbulence with two rather severe jolts. Then a

flight was made to Duluth and return to Minneapolis after which a mechanic noticed a discontinuity in the right wing. Upon inspection it was found that the front spar lower flange of the right wing had failed at a point corresponding to the initial failure found in the left wing of NC-93044

The aluminum alloy in the spar flanges of NC-93044 and NC-93042, designated as 75ST, was tested for chemical composition and strength at the National Bureau of Standards. It was found that the material was of the proper chemical composition, and that its tensile strength, yield strength, and elongation, were at or above the specifications for the material. However a photomicrograph of the mating portions of the spar flanges which had failed in NC-93044 and NC-93042 revealed that several fatigue cracks had developed

It is not definitely known how long a period of time would be required to develop the fractures found in NC-93044 and NC-93042. However, expert opinion concerning the failed right lower front spar flange in NC-93042 was that its appearance indicated that fatigue had developed over a period of time prior to actual separation.

Since high loads on the wing structure could be expected to have occurred when the airplane was flown into the thunderstorm in the vicinity of Winona, a study of weather conditions at the time of the flight formed an integral part of the investigation. United States Weather Bureau records showed that a high pressure area of cool air, centered in Canada north of Minnesota, extended into North Dakota, Minnesota, and Northern Wisconsin This cool air moved south and eastward behind a cold front which extended south westward across Wisconsin. At the time of the accident the front had become almost stationary near La Crosse, Wisconsin, 30 miles southeast of Winona. Above this cool air was warmer air which with high moisture content was convectively unstable Converging airflow in this warm air resulted in a vigorous squall line 70 to 75 miles in length behind the cold front, the effects of which extended downward from the cold air to the surface. Observations from the ground and in the air of the particular thunderstorm in this squall line into which NC-93044 flew, indicated that it was a well developed and severe storm. No evidence was found in the vicinity of Winona that a tornado had occurred, nor was any evidence found such as blown down trees, large broken tree branches, or damaged small structure which would have established the existence of unusually severe downdrafts

Several flights were in the vicinity of Winona for a period one hour before and one hour after the accident occurred The pilots of these flights described the storm as vicious and violent in appearance. Several flights successfully circumnavigated the storm arriving at their destination without incident. One air carrier flight, departing from Minneapolis at 1700, varied its course to the north to avoid the storm over Winona because of its black appearance and vivid cloud-to-ground and cloud-to-cloud lightning Another air carrier flight over the Winona area at approximately 1750 proceeded into the thunderstorm activity at an altitude of approximately 4,000 feet The pilot stated that the turbulence was more severe than he had ever encountered before No accurate determination can be made of the velocities of the vertical air currents within this thunderstorm. An answer in part, however, can be derived from the data accumulated by the Thunderstorm Project, and from statistics compiled by the National Advisory Committee for Aeronautics.

The Thunderstorm Project involved the combined efforts of the United States Weather Bureau, the National Advisory Committee for Aeronautics, and the United States Air Forces. Though no final report has been published, preliminary information has appeared in Weather Bureau and NACA Papers, in Air Forces Memoranda, and in a CAA Aviation Safety Release Number 304. Data were accumulated over a two-year period during which 1,400 traverses through thunderstorms in Ohio and Florida were flown. Seventy hours of flight time were actually spent inside thunderstorms.

The aircraft flown in the project was equipped with recorders to measure vertical air currents, or gust velocities The maximum gust was measured for each traverse of 3,000 feet in thunderstorms flown through in Florida, and for each

10-second interval of flight through thunderstorms in Ohio These traverses were made at altitudes varying from 5,000 to 26,000 feet. In summary, present data show no case of a flight between 5,000 and 6,000 feet where a gust was encountered with a vertical velocity in excess of 30 feet per second Flights conducted at altitudes in excess of 10,000 feet, however, encountered more violent gusts Between 15,000 and 16,000 feet the highest vertical velocities and the greatest frequencies for high velocities were found In one case, at an altitude of 15,000 feet, a gust velocity of 43 feet per second was recorded.

Information concerning the possibility of encountering high gust velocities is contained in statistics compiled by the National Advisory Committee for Aeronautics These statistics include recordings of gust velocities experienced in 9,240,000 miles of flight in the United States, South America, over the Pacific and Atlantic, and in Asia. They show that an airplane if flown for 1,500 hours at 200 miles per hour at various altitudes and under all types of conditions will encounter one gust with a velocity between 26 and 28 feet per second, three with velocities between 24 and 26 feet per second, and seven with a velocity between 22 and 24 feet per second. Gusts with lower velocities will be encountered with much greater frequency. For instance, the same airplane flying for 1,500 hours at 200 miles per hour and under the same conditions, will fly through 185,760 gusts with velocities from two to four feet per second, and 410,400 gusts with velocities from 3/10 to three feet per second.

The information received from the Thunderstorm Project and the National Advisory Committee for Aeronautics indicates that the maximum gust velocities which were present in the thunderstorm into which NC-93044 flew cannot be expected to have been in excess of 30 feet per second at altitudes of 6,000 feet or below.

Present design requirements contained in the Civil Air Regulations provide in effect that the Martin 202 be able to sustain limit gust velocities up to 30 feet per second at the limit load factor of 2 9 and a gust velocity of 53 feet per second at the ultimate load factor of 4.35 when encountered by the aircraft at a true air speed of 255 miles per hour According to Martin Aircraft data, the wing structure of the Martin 202 will not fail at an air speed of 255 miles per hour unless the gust has a velocity of 53 feet per second or more, and if the air speed is reduced to 170 miles per hour the gust must be in excess of 77 feet per second.

Prior to the certification of the Martin 202 the wing was subjected to cycling tests during which 1,885 applications of loads from 30 to 100 percent of the limit load were made The structure was then visually inspected, and no sign of any type of failure was found After the Winona accident this same test wing was again inspected. This time the zinc chromate paint was removed from the wing root fitting, the fitting was caustic etched, and then microscopically examined. This inspection revealed that the cycling tests had developed fatigue cracks in the lower front wing root fitting. In October of 1948, 17 Martin 202s in the Northwest fleet were examined for fatigue fractures. It was found that three of these airplanes had fatigue cracks in the corresponding locations to those which occurred in the front spars of NC-93044 and NC-93042 Of the 19 airplanes, the 17 examined in October plus NC-93044 and NC-93042, five had fatigue cracks in the lower fourth step down fitting of the front spars Three of these aircraft had fatigue cracks on both wings, and two of these aircraft had fatigue cracks on one wing.

Several tests were conducted by the manufacturer following the accident to determine what gust velocities would be required to fail the spar flanges after a fatigue crack had developed. According to these tests a gust velocity of between 38 and 48 feet per second would be required to fail the spar flange after a fatigue fracture had developed, such as found in the case of NC-93044, and a gust velocity of 25 to 35 feet per second would be required to fail the spar flange if the fatigue fracture was similar to the one found in NC-93042

The investigation of the Winona accident also included a complete examination of the maintenance and historical records of all Martin 202s owned and operated by Northwest Airlines These

records contained no entries which were material to the cause of the accident.

The manner in which thunderstorm weather is to be flown by Northwest Airlines' pilots has been left by the company to the discretion of the pilots. So far as could be determined, the practice in the 202 has been to throttle back, reducing air speed to approximately 170 miles per hour Flight into a thunderstorm or deviation from route to avoid a thunderstorm is also a matter of pilot judgment It is presumed that Captain Johnson, the pilot in N -93044, was familiar with thunderstorm flying He had a total of 5,502 flying hours, 311 of which were in the Martin 202, and had flown the route from Minneapolis to Chicago continuously since 1944.

Analysis

The separation in the left front lower spar flange of NC-93044 was followed by failure of the lower rear spar flange, and then by failure of the top connections of the outer wing to the center section. Without the left wing the airplane necessarily rolled to the left. A piece of fuselage structure found in the leading edge of the left wing, and a piece of the trailing edge of the left wing flap found imbedded in the right horizontal stabilizer showed that the left wing was struck by the top of the fuselage and the right horizontal stabilizer. As a result of this impact the left wing panel was broken into two parts, and the tail section was severed from the rest of the airplane

Separation of the lower front spar flange may have resulted from a gust which had a velocity in excess of that for which the airplane was designed, which is, as stated above, 53 feet per second at 255 mph. The second possibility is that the separation occurred as the result of a gust of a lower velocity, but after the strength of the material had been reduced by fatigue. Evidence received from the Thunderstorm Project, the National Advisory Committee for Aeronautics, and the meteorologists, all was to the effect that gust velocities in excess of 30 feet per second were extremely unlikely at the altitude that NC-93044 was flying

The subsequent test data from the Martin Company indicate that gust velocities well in excess of 30 feet per second would be required to fail a spar flange even after a fatigue crack had developed at the same place and of the same magnitude to the one found in NC-93044 This would tend to show that the spar of NC-93044 failed because of the joint action of fatigue and a gust of a higher velocity than that for which the airplane was designed. But, the Martin test data are no more conclusive than the evidence received concerning thunderstorms. A fatigue crack may be simulated, but not exactly duplicated. Imponderables still exist. For example, the roots of a fatigue crack may extend below that which is evident by microscopic examination.

A fatigue crack not only reduces the strength of a material, but serves as a nucleus for the very stress concentrations which cause the crack to extend and develop. Each application of load has its effect, and eventual failure is certain. Had the spar flange in NC-93044 not failed at Winona, it would have failed at a later date unless the defect from which the separation originated had been discovered. This was graphically illustrated by the failure of the spar flange in NC-93042 where the progression of fatigue over a relatively longer period of time than in NC-93044 was indicated, and where the severe jolts experienced during the flight from Chicago to Minneapolis were in all probability sufficient to cause complete separation.

The particular design of the connection of the lower flange for the front spar of the outer panel to the center panel for the Martin 202 is inducive to high local stress concentration. Hence, it is readily susceptible to fatigue. These high local stress concentrations are due to the following characteristics the fitting contained fillets of a small radius in the step down of 1/8 inch, there was a large sudden change in cross section in the fourth step down inboard from the attachment, increasing the depth to approximately twice its thickness, and the cross sectional area was designed to a high percentage of the ultimate strength of the material.

In view of the foregoing facts we are compelled to the conclusion that due to the high local stress concentrations of this particular design of the attachment

fitting, fatigue cracks had developed in the attachment fitting which so weakened the structure as to cause failure of the complete outer wing panel under the stress of the severe turbulence encountered in the thunderstorm.

At the present time the wing root fittings on the Martin 202s are being given frequent and thorough inspections for the development of fatigue cracks, and the operating speeds have been reduced ten percent. In addition, the front center section spar flange has been modified so as to include five steps or vertical increases in thickness to avoid any radical change in cross section. The radius in the fifth step fillet has been increased from 1/8 of an inch to 3/4 of an inch; two bolts have been added, and all parts have been polished. In general the above constitutes present corrective action approved by the Administrator of Civil Aeronautics. It is considered to be temporary in nature, but sufficient for safe operation until 3,000 hours of flight. After 3,000 hours of flight have been accumulated on the aircraft or before, the airplane will be modified at the Martin Company with a permanent correction which involves extensive structural changes to the wing.

Findings

Upon the basis of all available evidence the Board finds that

1. The carrier and crew were properly certificated.

2. The aircraft, a Martin 202, NC-93044, was flown as Northwest Airlines' Flight 421 departing from Chicago, Illinois, for Minneapolis, Minnesota, at 1550, August 29, 1948.

3. While descending en route to Minneapolis, Flight 421 reported, approximately six minutes before the accident, passing through the 7,000-foot altitude level and gave no indication of experiencing mechanical trouble.

4. Immediately prior to the accident, the aircraft flew into a severe thunderstorm in the vicinity of Winona, Minnesota, and, shortly thereafter, parts separated from the aircraft and fell to the ground.

5. The parts of the airplane above referred to struck the ground on a straight line bearing 335 degrees, approximating the flight path of the airplane, and covering a distance of 1.8 miles. The first sections found along the flight path were the outer portion of the outer left wing panel, the tail section, and the inner portion of the outer left wing panel.

6. The fillet of the fourth step inboard of the lower left front center section spar flange revealed a fatigue fracture approximately 7/8 of an inch long and 3/32 of an inch deep. The remaining area failed in tension.

7. The separation which occurred in the lower front center section spar flange was followed by a separation of the left rear spar lower flange and the separation of the top connections of the outer panel to the center section of the wing.

8. The airplane, deprived of the lift of the left wing, rolled to the left and crashed approximately 4 miles northwest of Winona, Minnesota.

9. Several hours after the subject accident, fatigue cracks similar to those found in NC-93044 were found in the wing root fittings of another Martin 202, NC-93042. This airplane had flown through the same storm area about an hour after the accident. A complete separation had occurred in the front spar lower flange of the right wing of NC-93042 at a point corresponding to the initial failure which was found in the left wing of NC-93044. Two days after the subject accident, three other Martin 202 aircraft, upon inspection, were found to contain fatigue cracks in similar locations to those found in NC-93044 and NC-93042.

10. A wing specimen of a Martin 202 which had been subjected to cycling tests prior to type certification of the aircraft was microscopically examined after the Winona accident, at which time fatigue cracks were found in the wing root fitting which had been developed by the cycling test.

Probable Cause

The Board determines that the probable cause of this accident was the loss of the outer panel of the left wing which separated from the aircraft as a result of a fatigue crack in the left front outer panel attachment fitting which had been induced by a faulty design of that fitting, the fatigue crack having been aggravated by severe turbulence encountered in the thunderstorm

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BY THE CIVIL AERONAUTICS BOARD

/s/ JOSEPH J. O'CONNELL, JR
/s/ OSWALD RYAN
/s/ JOSH LEE
/s/ HAROLD A. JONES
/s/ RUSSELL B. ADAMS

Supplemental Data

Investigation and Hearing

Notification of this accident was given by eyewitnesses to Northwest Airlines, Inc , who in turn notified the Civil Aeronautics Board. Upon notification an investigation was immediately initiated in accordance with the Civil Aeronautics Act of 1938, as amended. On October 14 and 15, 1948, a public hearing was held in Winona, Minnesota.

Air Carrier

Northwest Airlines, Inc., is a Minnesota Corporation, having its principal place of business at 1885 University Avenue, St. Paul, Minnesota. The company is the holder of a certificate of public convenience and necessity issued by the Civil Aeronautics Board which authorized, among other things, operations between Chicago, Illinois, and Minneapolis-St. Paul, Minnesota. It was over this segment that Northwest's Flight 421 was flying.

Flight Personnel

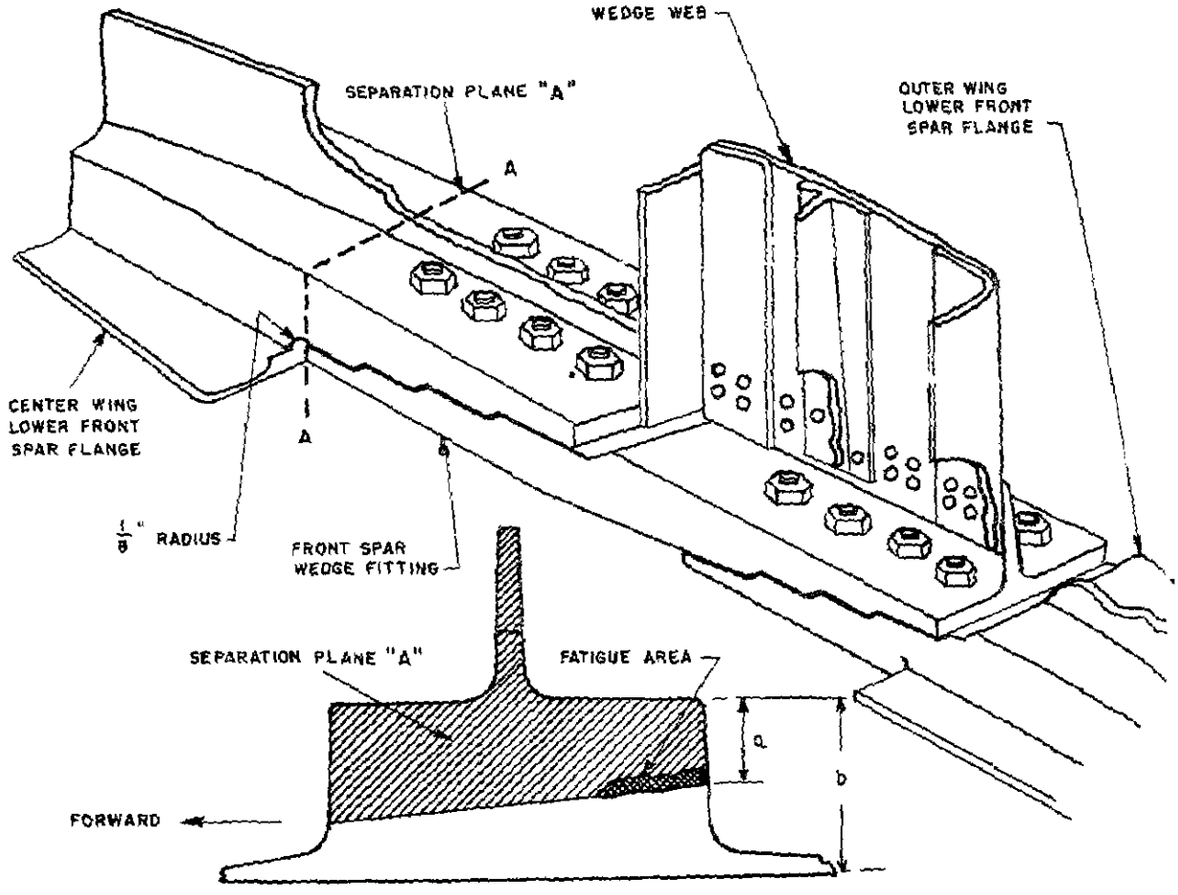
Captain Robert L. Johnson, age 30, held an Airline Pilot Certificate No. 47715, with 0-7200 hp rating—multi and single engine land. He had a total of 5,502 flying hours, 311 of which were in Martin 202 equipment. He was employed as a second pilot trainee on February 26, 1942, and assigned to second pilot duties on March 12, 1942 He completed first pilot transition training and was assigned as a first pilot on June 19, 1944 For the three days preceding this accident, Captain Johnson flew 9 hours and had a rest period of one day His last Civil Aeronautics Administration physical examination was given June 2[illegible], 1948

David F. Brenner, age 27, held Commercial Certificate No. 72277 with instrument rating. He had a total of 2,380 flying hours, 155 of which were in Martin 202 equipment. He was employed as a second pilot trainee on March 29, 1943, and assigned as a second pilot on May 12, 1943. Second Pilot Brenner had flown seven hours and had a rest period of two days during the three days preceding the flight. His last Civil Aeronautics Administration physical examination was on January 23, 1948

The Aircraft

NC-93044 was a Martin 202 aircraft certificated by the Administrator of Civil Aeronautics. It had been placed in scheduled operation March 16, 1947, and at the time of the accident had a total of 1,321 flight hours. The engines were Pratt and Whitney's R-2800-CA18. Both the No. 1 and the No. 2 engines had a total of 625 hours since new and neither had been overhauled. The propellers were Hamilton Standard Hydromatics. The No 1 propeller had a total time of 1,083 hours, 387 being since overhaul The No 2 propeller had a total of 692 hours since new.

WING ROOT FITTING



SCHEMATIC SECTION OF SEPARATION OF LOWER FLANGE SHOWING FATIGUE AREA AND ALSO SUDDEN INCREASE OF DEPTH OF FLANGE "a" TO APPROXIMATELY TWICE THE DEPTH AS INDICATED BY "b"

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